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LAND LOCOMOTION LABORATORY

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BEHAVIOR OF PNEUMATIC TIRE

By

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June 1964

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WARREN, MICHIGAN

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OBJECTIVE

Investigate and analyze the performance of driven pneumatic tires in soft soil.

RESULTS

The inherent inadequacies of the existing test apparatus were made known through preliminary test runs. Considerable effort was spent in modifying and redesigning the test apparatus.

CONCLUSIONS

Preliminary test runs showed that it was not feasible nor practical to attempt to filter out or analyze interaction effects on the desired readout data. A major redesign of portions of the apparatus was decided upon.

ADMINISTRATIVE INFORMATION

This program was supervised and conducted by the Land Locomotion Laboratory of ATAC, under D/A Project No. 597-01-006, Project No. 5016.11.84400.

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ABSTRACT

The existing fundamental equations used to describe the performance of a wheel operating in soft soils require modification if they are to accept a deforming pneumatic tire. These modifications are based on new variables characteristic to the tire including tire deflection, carcass stiffness, and inflation pressure.

The proposed program calls for the testing of driven pneumatic tires under various load, slip inflation pressure and soil conditions. Using these variables as input data drawbar-pull, slip, deflection, rolling resistance and drive torque will be measured.

The present state of the program has revolved around the evaluation and modification of the existing test apparatus. Preliminary test runs indicated a need for remodifying the design of the apparatus. The problems encountered with the apparatus are discussed herein.

LIST OF FIGURES

INTRODUCTION

The lack of a universal wheel dynamometer has been a prime factor in the relatively slow development of tire performance evaluation and prediction. Many tire dynamometers have been designed for the purpose of studying individual variables, or small groups of variables, influencing tire performance characteristics such as drawbar-pull, slip, sinkage, load and deflection. While these dynamometers permit one to focus on important items, they have not permitted the investigation of the full range of variables acting during a given instant. The contribution of each variable for a given run is necessary both for evaluation and performance prediction.

The reason behind the individual variable or small group variable study has been the difficulty encountered in the transducer sensing unit due to interaction effects of one variable on another. It has been a simple enough procedure to pick up the desired unknown through a transducer, but oftentimes, a variety of interaction forces accompany the desired unknown. Filtering and analyzing techniques become cumbersome to the point that it has been neither practical nor feasible to extract the unknown from the readout data.

Thus, the design of a wheel dynamometer has been limited to methods which enable data pickup of variables which do not cause interaction effects. Clearly, the problem of designing a universal wheel dynamometer is one of multivariable control with respect to the transducer readout.

SUMMARY

The original configuration of the test apparatus is discussed in view of the force system acting on the transducer. A method used to account for the interaction between the wheel torque and the drawbar pull transducers is also presented. Results of the final check on the drawbar-pull transducers are also presented.

The redesigned portion of the apparatus is shown schematically and concepts behind the redesign are discussed.

CONCLUSIONS

The position of the drawbar-pull transducers in the original configuration permitted a variety of secondary restraining forces to affect the drawbar-pull readout. The secondary force effects varied between -50% to +100% of the total force indicated on the transducer. The effects were nonlinear and it was considered too impractical to construct a correction curve.

The most sensible approach to the problem of measuring drawbar-pull was to redesign a portion of the apparatus in a manner which would eliminate the necessity of correcting for torque interaction and restraining effects.

RECOMMENDATIONS

It is recommended that the redesigned apparatus be subjected to a series of evaluation trial runs before actual tests are begun. Furthermore, the problems encountered with this piece of equipment can be used as criteria for design of the proposed universal wheel dynamometer presently under consideration.

OBJECT

The primary object of this program is to analyze the performance of driven pneumatic tires in soft soils for the purpose of modifying the existing performance equations for rigid wheels to accept a deforming pneumatic tire. The program is thus divided into two sections: experimental testing and theoretical development based on experimental results. The experimental segment will consist of measuring those variables common to both types of tires plus the added variables peculiar to the pneumatic tire such as tire deflection, carcass stiffness and inflation pressure. The theoretical phase will consist of altering the existing rigid wheel equations by inserting the variables of tire deflection and inflation pressure which will then make the performance equations applicable to a deflecting pneumatic tire.

The secondary object of the program is the evaluation of the existing tire test rig in view of its capabilities of measuring the desired data input to the performance equations. This secondary object is the immediate concern of this report. The approach used to evaluate the tire rig has involved the individual calibration of the transducers for drawbar-pull, wheel torque, sinkage, tire deflection, and wheel slip, as well as, the interactions effects occurring between drawbar-pull and torque, static and dynamic load. The drawbar-pull transducers were also checked against a known drawbar load.

CALIBRATION

As was stated earlier, the problem of a dynamometer design, with respect to the transducers, is a problem of multivariable control. The initial configuration of the test apparatus revealed that this problem was overlooked in the original design, and that interaction effects were transmitted from the applied wheel torque to the drawbar load links. See Figure 1.

Figure 1-a illustrates the desired readout for the drawbar-pull shown. If pure drawbar is applied at the axle, a horizontal force F_1 will induce a strain reading in the drawbar load links. Figure 1-b shows the effects of a moment of torque applied at the wheel on the load links. The applied torque is restrained by the soil, R, and pin restraints of F_1' and F_2'. The restraint force F_1' induces a strain in the load link which is a combined reading of drawbar-pull and moment interaction. In order to obtain the true drawbar-pull at the axle height, the effect of the torque on the load link must be subtracted from the total readout. This required a separate calibration of the load links for drawbar alone and also, a calibration of drawbar and torque simultaneously. Figure 2 shows the calibration schematic for pure drawbar pull induced readings on the load links.

The screw jack was used to apply a load to the axle of 3000 lb. in 500 lb. increments, measured by the load cell. The corresponding load links strain readings were then recorded. These strain readings represented a pure drawbar applied at the axle. The rig was supported from above at a point which would not interfere with the application of drawbar load.

Figure 3 shows the calibration of the combined torque and drawbar effect on the load links.

An external torque, M, was applied to the wheel. The restraining force, R, in the horizontal bar was located 12 inches from the axle center. As a result, the load cell measured a drawbar load, R, and also a torque, M = R x 12 associated with this drawbar load. The combined torque and restraining force induced a pin reaction P_1', which, in turn, caused a strain in the load links. The strain recorded in the load links was then plotted against the corresponding torque and drawbar load.

From the two separate calibrations, it was now possible to extract the true drawbar-pull associated with a given torque for a given test run.

The two calibrations used to extract the true drawbar pull are shown in Figures 4a and 4b.

Determination of the actual drawbar-pull for a given run is made as follows:

From the torque obtained, the effect of the moment interaction on the load links is obtained from curve 4-b, value Δ. The effect of the moment on the load links is greater than the effect of the drawbar-pull. This can be seen from the slope of the two calibration curves. It must be recalled, however, that the value Δ from the calibration curve represents the effect of both a moment and a force R at a distance of one foot below the axle height. This value of R can be removed by superimposing the pure drawbar curve of figure 4-a on figure 4-b as shown by the dotted line since the abscissa values for torque and force are numerically equal. The value of a-b is, therefore, the effect of the torque alone on the load links. Therefore, the true drawbar-pull is obtained by subtracting the value of a-b from the total readout on the load links. This procedure can be written in equation form as:

$$\Delta_{DBP} = \Delta_T - (\Delta - \Delta_R)$$

where:

Δ_{DBP} = Drawbar-pull strain

Δ_T = Readout strain on the load links

Δ = Torque plus reaction R strain

Δ_R = Reaction R strain

Provisions were made to check the accuracy of the above system for measuring drawbar-pull by means of a towing sled. A sled was attached to the rear of the test carriage and a load cell placed between the carriage and sled. The actual drawbar-pull measured by this load cell was compared to the drawbar-pull obtained from the reduction of the load link readout data. The results were very discouraging, as can be seen in Figure 6. The amount of scatter between test values, as well as the cumbersome method of data reduction, pointed out the inadequacy of the configuration of the test rig. A variety of secondary interactions were observed from the sinking of the tire, different tire loads, and the restraining forces due to the redundant members in the apparatus.

NEW DESIGN

The redesigned portion of the rig was based on two basic concepts. First, the position of the drawbar transducer should be such that the drawbar load is measured directly; secondly, that removal of the transducer from the system would cause collapse of the apparatus. This second concept prevents the drawbar force from being distributed to other restraining members. Figure 5 shows the redesigned portion of the rig which consists of another parallel link.

Since the load cell is located along the horizontal axis perpendicular to the wheel axle, the only force measured by the load cell is the drawbar-pull. The pin connections on either end of the load cell prevent any bending moment to be carried by the load cell link. The pin connection at the top of the forward frame allows rotation due to the forward motion of the apparatus. The use of the pin connections prevents restraints from occurring in members of the structure that would detract from the load cell restraint. Basically, the new link was designed to obtain a direct readout of drawbar-pull without interaction effects. Achievement of a multivariable control transducer system in the above manner should facilitate the collection of all necessary input data for the performance equation.

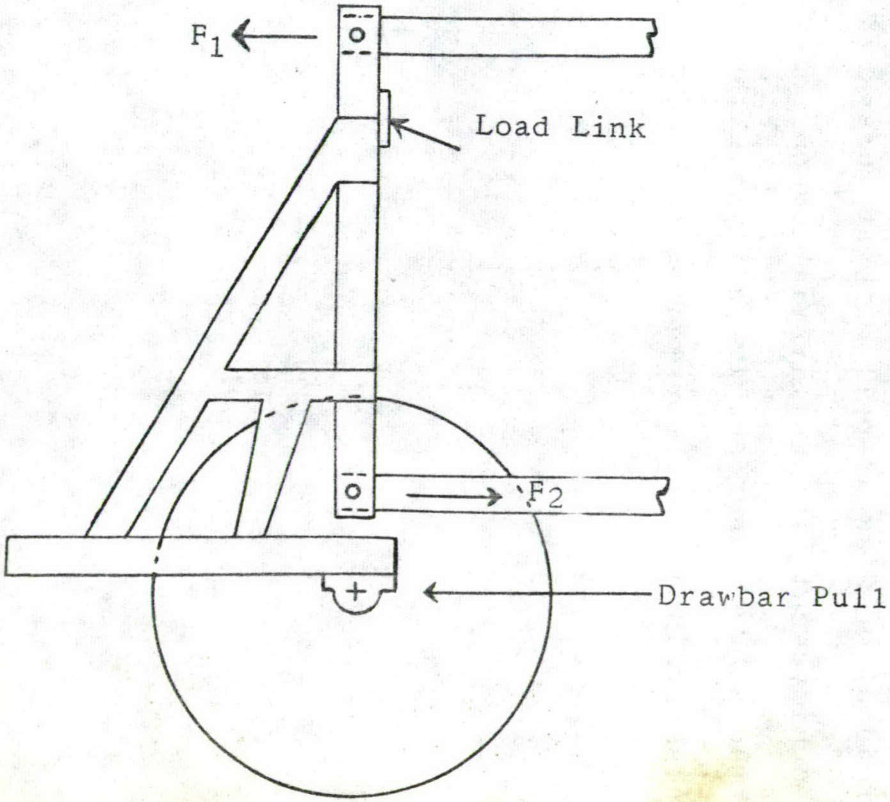


Fig.1a.

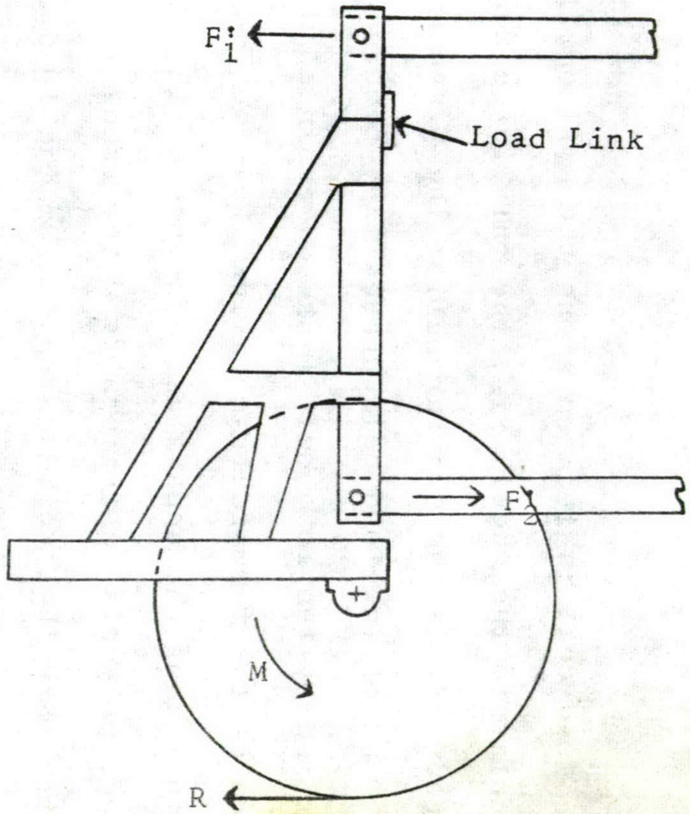
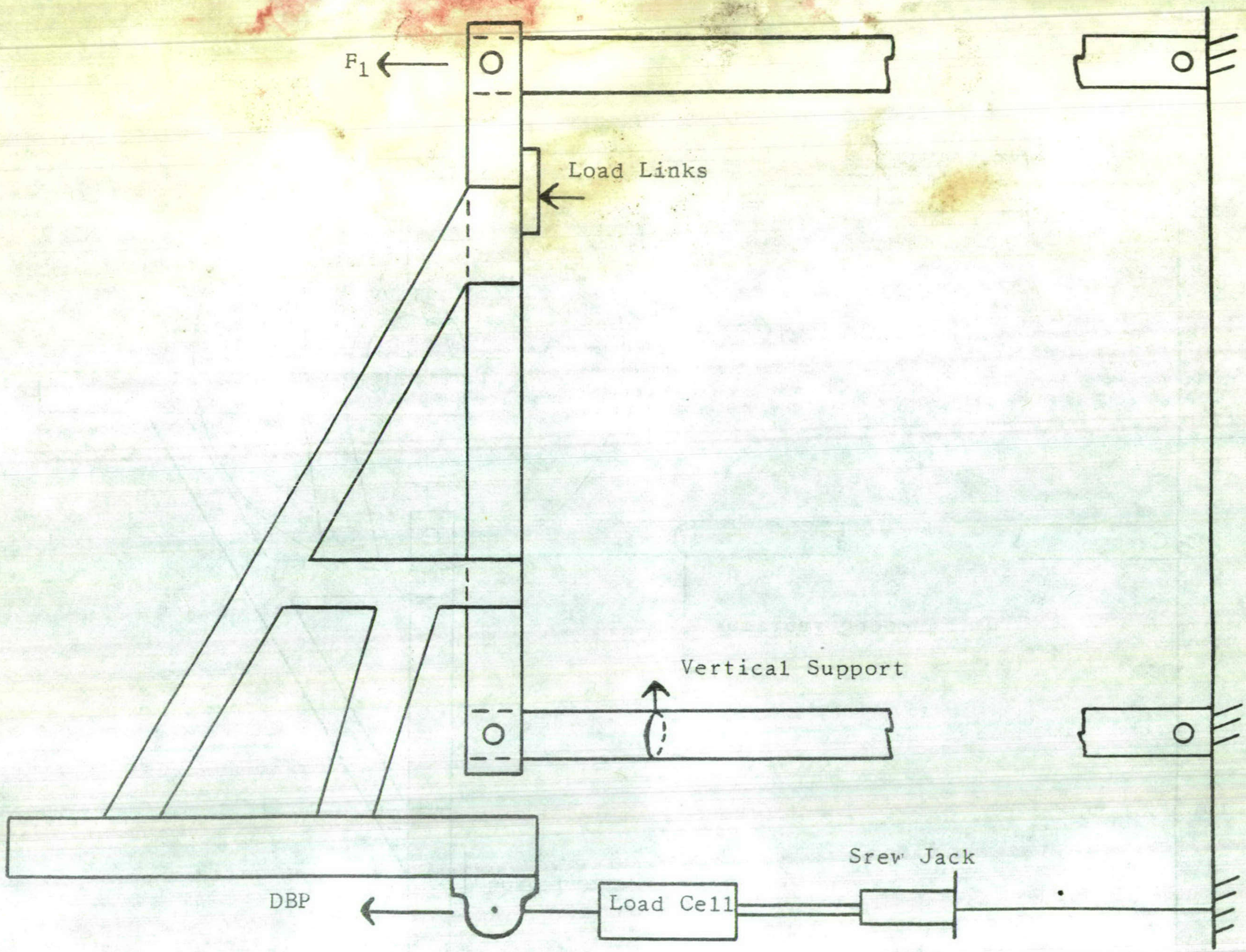


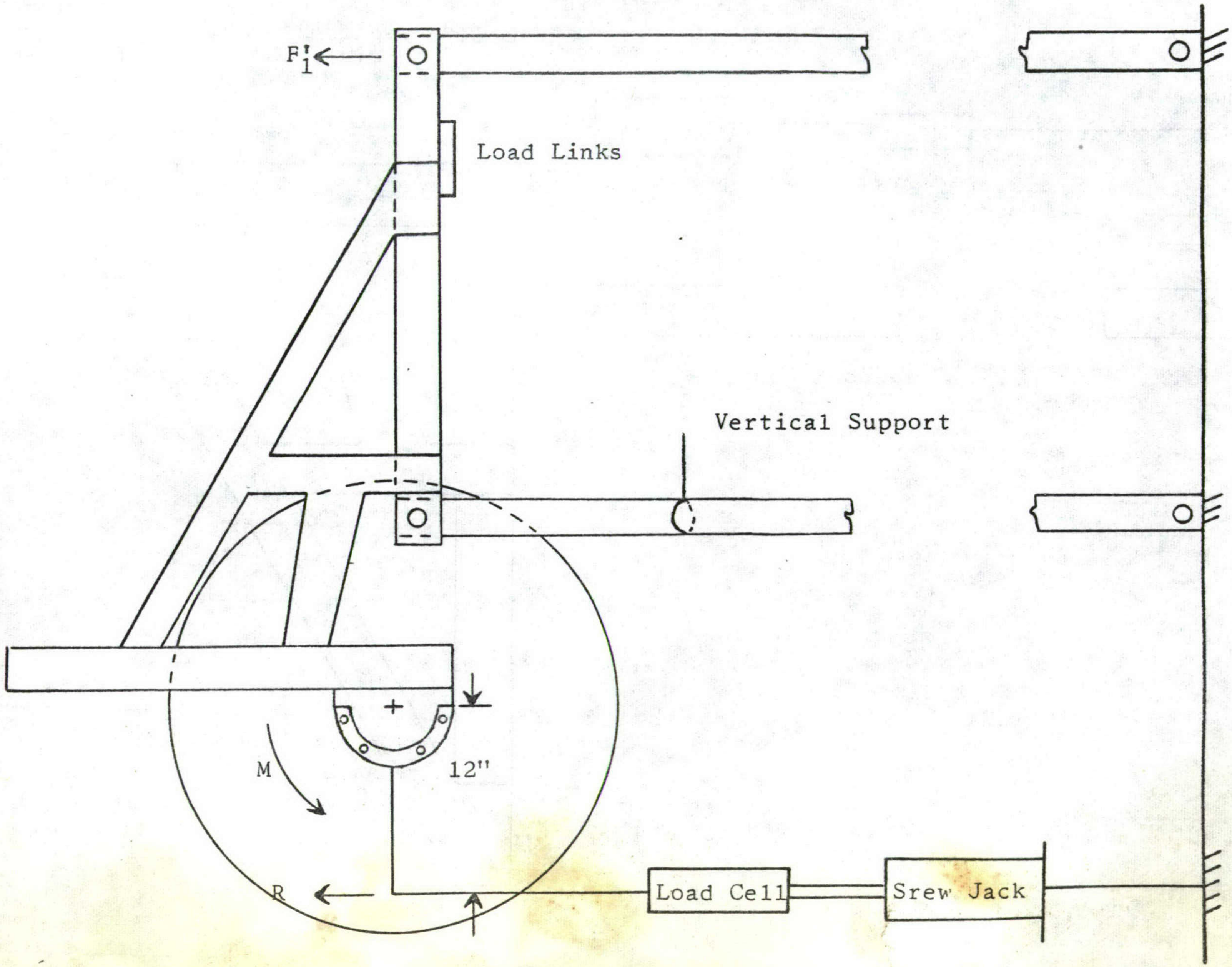
Fig. 1b.

Tire Test Rig Showing Provisions for Drawbar Pull(1a)and Torque(1b) Measurements.

Figure 1



Drawbar Pull Calibration Arrangement.
Figure 2.



Combined Drawbar Pull and Torque Calibration Arrangement

Figure 3

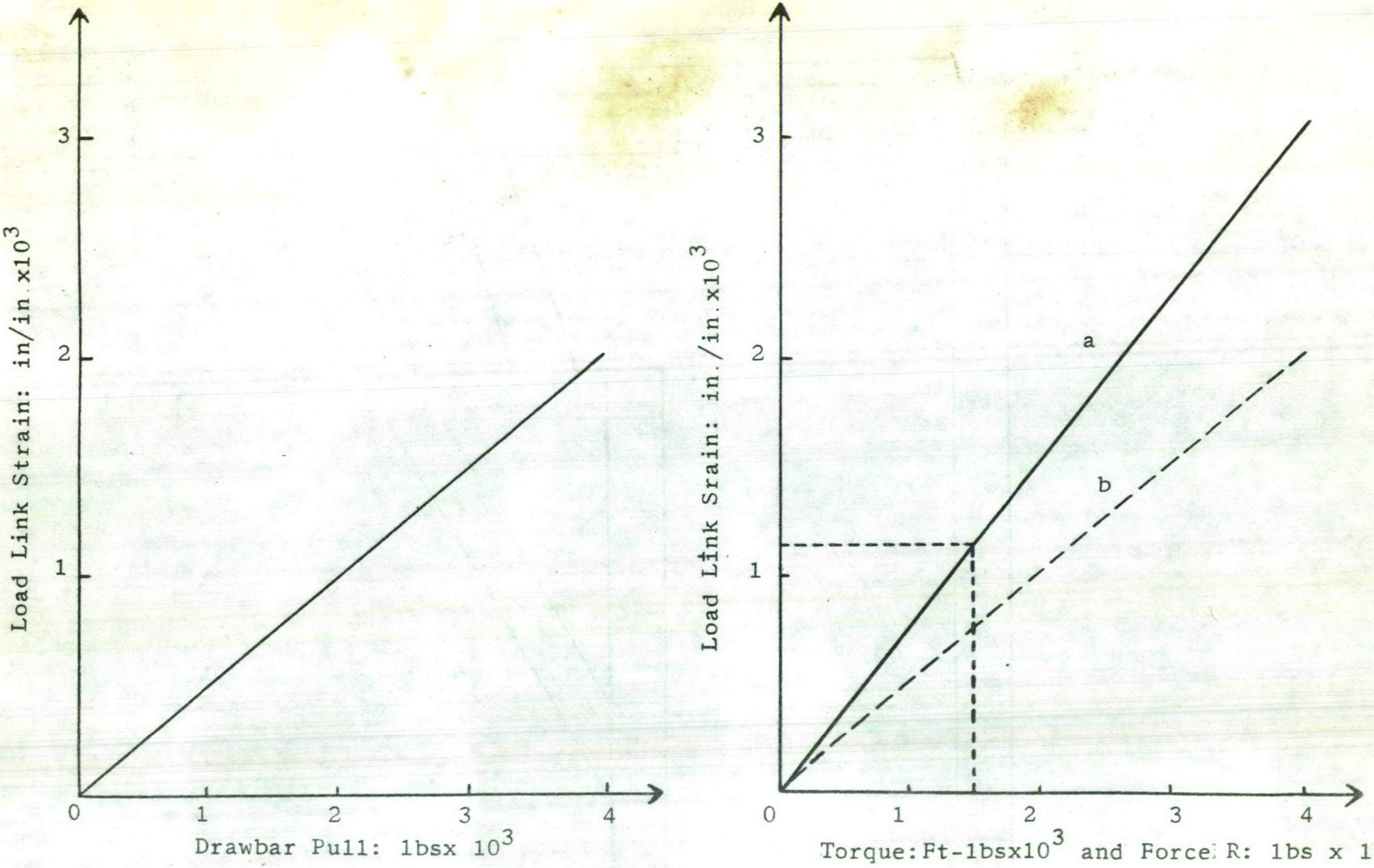


Figure 4. Calibration Curves.

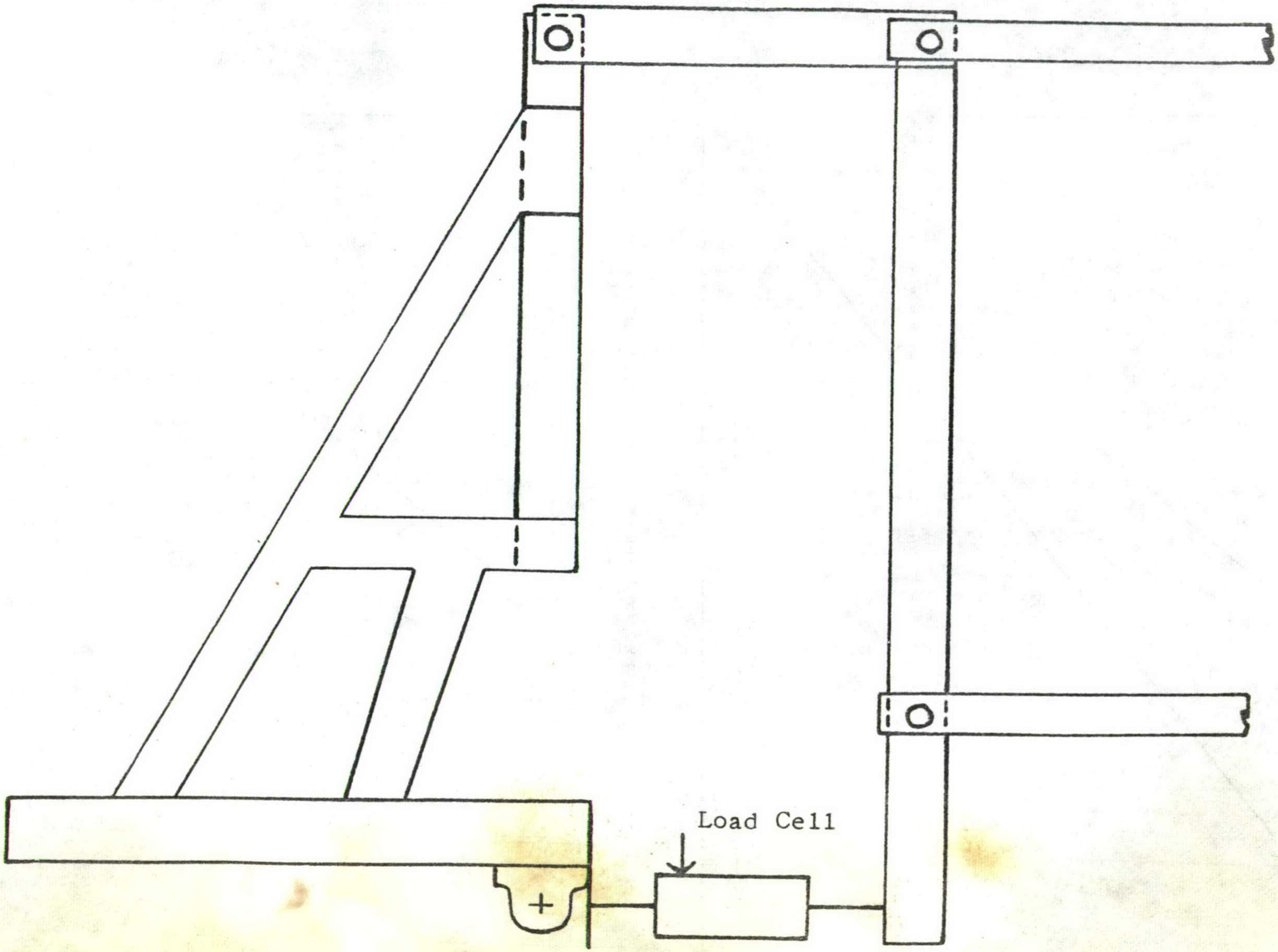


Figure 5. New Design with Parallel Link Addition.

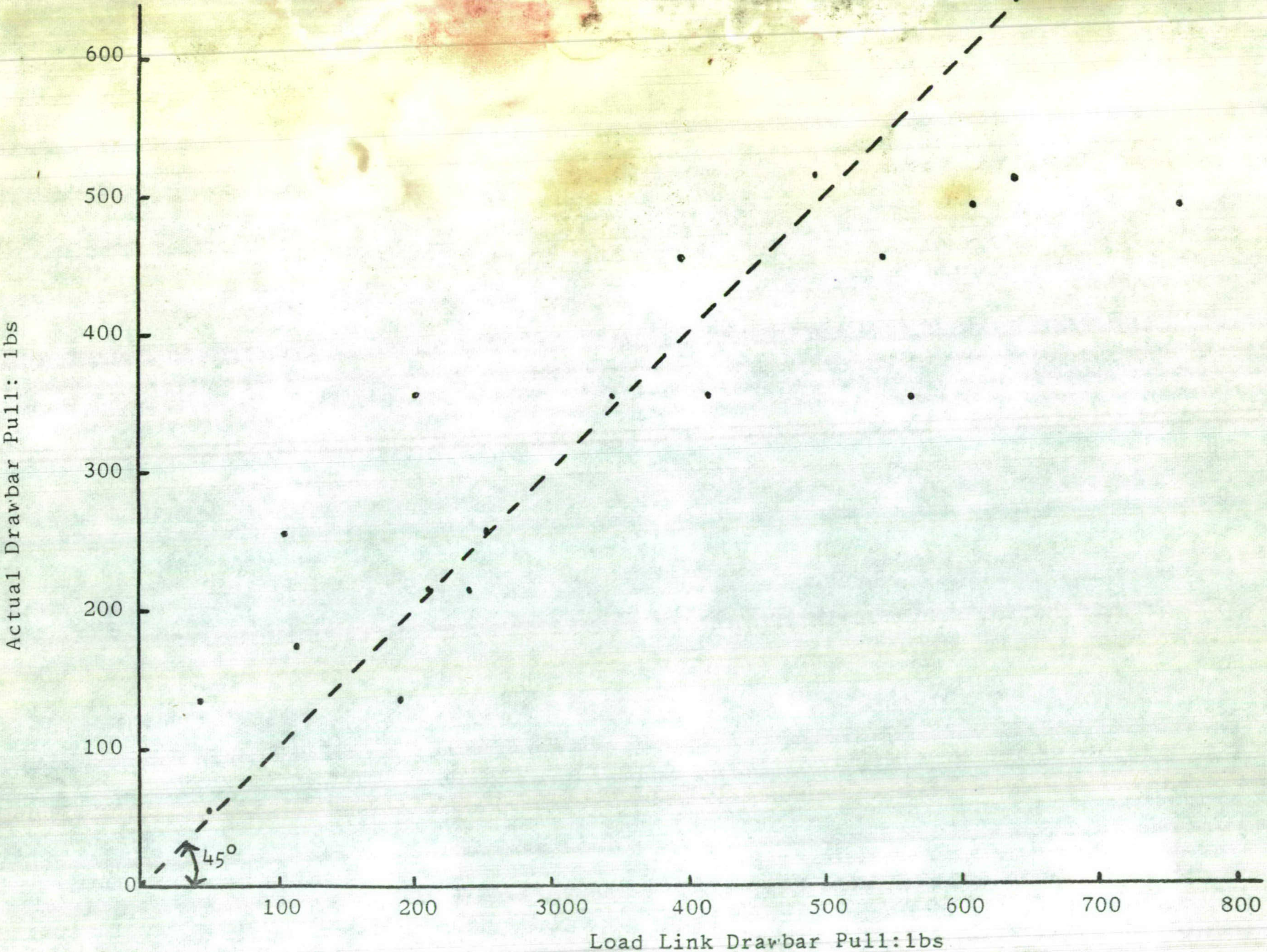


Figure 6 Comparison of Actual and Load Link Drawbar Pull

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